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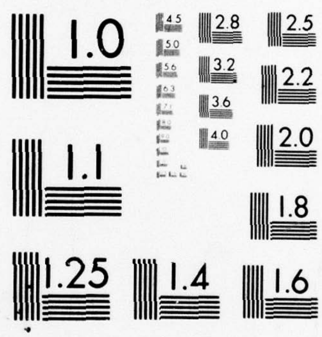


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# CHARACTERISTICS OF THE FORMATION OF RIVER SLOPE RUN-OFF IN PERMAFROST REGIONS

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This report discusses questions concerning the formation of a slope runoff in the case of a deep lie of the permafrost water confining layer and available length slope thickness of the thaw layer. It is under such conditions that most floods form in mountainous rivers of the northeastern USSR.

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NOTICE

## CHARACTERISTICS OF THE FORMATION OF RIVER SLOPE RUN-OFF IN PERMAFROST REGIONS

A slope is a dynamic system with distributed parameters. This system accomplishes a certain transformation as the result of which the input function - precipitation - a (l, z, t) is transformed into a different function - slope run-off Q (l, z, t), and

$$Q(l, z, t) = A \left\{a(l, z, t)\right\}. \tag{1}$$

In expression (1), symbol A is the operator of a dynamic system that can be of any type and complexity. As a rule, the function of the system is described by differential equations and therefore transform A pertains to solving a differential equation which links the input and output functions.

Depending upon the characteristics of the underlying surface, the very same precipitation input function can correspond to different system reactions. Thus, depending upon the relationship between the intensity of precipitation $a_l$, the intensity of drenching i, and the filtration capacity of the upper layer, the run-off can occur in any one of the following forms: 1) a surface run-off, when horizontal filtration is infinitesimally smally, and $i_t < a$; 2) surface and contact run-off, when there is a copious slope run-off observed in the upper friable layer in addition to surface run-off; 3) surface, contact, and sub-surface run-off; 4) surface and sub-surface run-off; 5) contact and sub-surface run-off; 6) sub-surface. A sub-surface slope run-off occurs in cases when $\delta H < x_t$ ($\delta$ - free capacity of the friable layer, H - thickness of the friable layer over the relative water confining stratum, $x_t$ - the layer of precipitation soaked into the soil).

Below we shall dwell on certain questions of the formation of a slope run-off in the case of a deep lie of the permafrost water confining layer ($\delta H > x_t$) and a variable length slope thickness of the thaw layer. It is precisely under such conditions that most floods form in mountainous rivers of the northeastern USSR. The investigation of the loss of the flood run-off, carried out according to data of the Bomnaksk and Kolymsk run-off monitoring stations, which are located in the zone of universal distribution of permafrost, has shown that total losses $P_0$ exceed the initial $P_i$ 4 to 6 times. It is possible that such a deviation in the complete absence of filtration into the underlying permafrost water confining stratum (2) occurs because water formation along the length of the slope is not being simultaneously observed. In the opinion of the authors, one of the causes of this non-simultaneity is the non-uniform lengthwise distribution of the thickness of the seasonal thaw layer on the slope. A study of the materials of permafrost surveys carried out at different times in the watersheds of the Kolymsk and Bomnaksk run-off monitoring stations has made it possible to get an idea of certain principles of the spatial distribution of the depths of melting of the active layer. In general, the melting depth increases in the direction toward the watershed and this principle can be approximately described by the following equation

$$H_l = (H_{max} - H_{min})\left(1 - \frac{l}{l_{max}}\right)^{n} + H_{min}, \tag{2}$$

where $H_l$ is the depth of the seasonal layer at a distance l from the watershed; $H_{max}$ and $H_{min}$ are the maximum and minimum depths of thawing at the time of the survey.

On a linear graph H = f (l), parameter n = 1, with convex contours - n<1, and with concave - n > 1.

Another cause of the non-simultaneity of water formation along slope length lies in the peculiarities of moistening of the mountain slopes of regions where permafrost is universal. According to B. N. Dostovalov and V. A. Kudryavtsev (3), on a slope beginning from the watershed line to the local erosion base line, i.e., to the valley thalweg, one can arbitrarily identify three zones where the features of ground water feed of the super-permafrost water table, their lifetime and the degree of their effect on the distribution of moisture in the thaw layer are different.

Under the effect of these factors, water formation begins earliest in the lower part of the slope, i.e., in the zone of least depth of thawing and greatest previous moistness. In the process of precipitation, the front of water formation will gradually shift up the slope. Since the area of formation continuously increases in time, then naturally the losses on soil retention will have a diminishing character. The distribution of losses on retention along the length of a slope can be expressed by the following equation

$$P_l = P_{max} \left(\frac{l}{l_{max}}\right)^m, \tag{3}$$

where $P_l$ is the layer of losses due to soil retention over a distance l from the water receiver; $P_{max}$ is the layer of losses on soil retention at the watershed.

If the beginning of the calculation of l is moved to the watershed, then (3) is written in the following form

$$P_l = P_{max} \left(1 - \frac{l}{l_{max}}\right)^m. \tag{4}$$

It is easy to show that

$$P_{max} = (m + 1)\ P_z, \tag{5}$$

where $P_z$ - losses on soil retention,

$$P_z = P_0 - P_n. \tag{6}$$

By substituting (5) in (3), we obtain

$$P_l = (m+1)\left(\frac{l}{l_{max}}\right)^m P_z \tag{7}$$

Obviously, the position of the water formation front on the slope is determined from the identity

$$\int_0^{t_\phi} a_t\, dt = (m+1)\left(\frac{l_\phi}{l_{max}}\right)^m P_3 , \tag{8}$$

whence

$$l_\phi = \left[\frac{\bar{a}_{t_\phi} t_\phi}{(m+1)P_3}\right]^{\frac{1}{m}} l_{max} = \left[\frac{x_{t_\phi}}{(m+1)P_3}\right]^{\frac{1}{m}} l_{max} \tag{9}$$

If $l_\phi < {}_{max}$, i.e., $\left[\frac{x_T}{(m+1)P_3}\right]^{\frac{1}{m}} < 1$ by the time it stops raining, then only the lower part of the slope participates in run-off formation. When $\left[\frac{x_T}{(m+1)P_3}\right]^{\frac{1}{m}} > 1$, beginning with a moment in time $t = \tau_\phi$, and over the course of $T - \tau_\phi$, the run-off will form on the entire slope.

According to formula (9), the expressions $\frac{l_\phi}{l_{max}}$ were calculated for all Kolymsk and Bomnaksk run-off monitoring stations for all water flows. Most of the floods in the water collection basins of the Bomnaksk run-off monitoring station form when $\frac{l_\phi}{l_{max}} < 1$, i.e., by the time it stops raining the water formation front does not reach the watershed. The degree of participation of the water collection area in the run-off depends both upon the amount of precipitation and on previous moisture content. The formation of floods in the upper water stretches of the Kolyma River even occur with the complete participation of the entire basin area in the run-off with comparatively small amounts of precipitation (10 - 15 mm).

The time of inclusion of the entire slope in the run-off can be determined according to formula (9), having assumed $t_\phi = \tau_\phi$ and $l_\phi = l_{max}$; then

$$\tau_\phi = \frac{(m+1)P_3}{[illegible]} \tag{10}$$

We shall examine how the rainfall graph affects $\tau_\phi$. For convenience of the plotting, we shall assign a build-up in the precipitation layer in time to the indiciative graph

$$x_t = x_T \left(\frac{t}{T}\right)^s. \tag{11}$$

When $s > 1$ — intensity of rainfall increases in time; when $s < 1$ — rainfall decreases in time, and when $s = 1$ — rainfall remains constant.

The intensity of precipitation averaged over a time t is expressed in the following way:

$$\bar{a}_t = \frac{x_T t^{s-1}}{T^s}. \tag{12}$$

By substituting (12) in (9), we obtain an expression which determines the position of the water formation front depending upon the rainfall graph:

$$l_\phi = \left[\frac{x_T t_\phi^s}{(m+1) T^s P_s}\right]^{\frac{1}{m}} l_{max}. \tag{13}$$

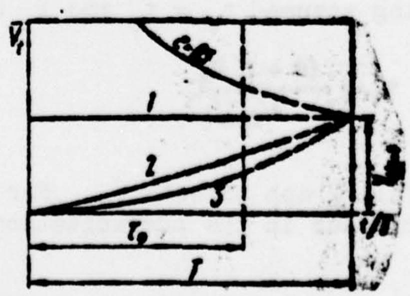
The figure shows the change in the average rate of movement of the water formation front with the increase in the period of averaging during different types of rainfall. When $\tau_\phi < t$, the highest rate will exist in a case when $s < 1$, i.e., when rainfalls with *diminishing intensity* are included in the total slope run-off when one has other rainfall graphs. Consequently, the shape of the slope hydrograph will totally depend upon the intensity course of precipitation in time. One estimates the parameter m according to observation materials taken at the Bomnaksk run-off monitoring station. Its average value is 1.5. With respect to losses on soil retention, then they can be determined in the following manner when $\tau_\phi < T$:

$$P_s = \int_{t_H}^{T} (a_t - y_t)\,dt = X_{T_\lambda} - P_H - Y_{T_\lambda} \tag{14}$$

when $\tau_\phi < T$

$$P_s = \int_{t_H}^{\tau_\phi} (a_t - y_t)\,dt = X_{\tau_\phi} - Y_{\tau_\phi} = X_{T_\lambda} - P_H - Y_{T_\lambda} \tag{15}$$

where $t_H$ is the onset time of water formation; $T_\lambda$ is the duration of rainfall.



For practical purposes, one can recommend calculating $P_Z$ and $P_H$ depending on characteristics of the previous moisture content and thickness of the thaw layer. Such relationships are cited in a work (1), where, for example, the total losses are correlated with the index of preceding moisture content $I_n$ and the indirect characteristic of the thawing depth - the total of positive air temperatures $\Sigma t_H$.

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SINGULARITIES OF RIVER SLOPE RUNOFF FORMATION IN PERENNIAL PERMAFROST REGIONS

Summary

A case of slope water formation under deep deposit of permafrost impervious bed and variable (over the slope length) seasonal melting layer is discussed.